Specification:

[0034] As best illustrated in FIGS. 3, 5A and 5B, actuator 32 is held in its axial position within outer housing 22 at its one end as a result of threaded clamp 30a providing an inward axial load on actuator 32 by way of a spacer 39a, valve ~~housing~~ seat 40a and spacer rings 42a and 44a. At its other end, actuator 32 is held in its axial position as a result of threaded clamp 30b providing an inward axial load on actuator 32 by way of a spacer 39b, valve ~~housing~~ seat 40b and spacer rings 42b and 44b. Spacers 39a and 39b are generally disk shaped washers formed of a somewhat resilient material, such as a polymer sold in association with the trademark Vespel. ~~Retaining~~ Spacer rings 42a and 44a (and 42b and 44b) are annular nested rings with ring 42a having a smaller diameter than ring 44a. The outer diameter of ring 42a is about equal to the diameter of actuator 32. Rings 42a, 42b, 44a, and 44b, too, are preferably formed of Vespel.

[0035] The spacer rings 44a and 44b serve three functions. First, spacer rings 44a and 44b act as load springs to provide an axial pre-load to actuator 32. Second, they form a seal at each end of the spacer ~~44~~39a and ~~44~~39b. Thirdly, they partially define pumping chambers 72a and 72b, as detailed below.

[0047] Rings ~~38~~ 44 loaded by the force of threaded clamps 30a and 30b compress actuator 32 so that in the absence of a magnetic field, actuator 32 is contracted lengthwise. In the presence of a magnetic field actuator 32 lengthens in an axial direction, against the force exerted by rings ~~38~~ 44. All the while the volume of actuator 32 remains constant. As such, an axial lengthening is accompanied by a radial contraction of actuator 32.

[0053] As sheath 34 is made of a hard material such as ceramic, a radial expansion of actuator ~~38~~ 32 and resulting displacement of the fluid within cavity 74 is resisted by sheath 34.

[0054] Specifically, as illustrated in exaggeration in FIG. 8, in a first state, actuator 32 has a minimum length and a maximum diameter. Chambers 72a and 72b, in turn, have increased volumes, resulting in reduced pressures therein, allowing passage of liquid through valves 24a and 24b, and preventing flow of liquid through valves 28a and 28b. Liquid may thus be drawn into chambers 72a and 72b. At the same time, the volume of chamber 74 is reduced, and liquid therein is displaced by actuator 32. One-way valve 26a ~~remains closed~~ is opened, while valve 26b is ~~opened~~ closed, allowing fluid to be expelled from axial chamber 74.

[0055] As current flow of the source 80 varies, actuator 32 begins to expand axially and contract radially. One quarter period of oscillation of the electric source later, actuator 32 is in a second state, as illustrated in exaggeration in FIG. 9. In this state, actuator 32 has maximum length, and minimum diameter. As the length of actuator 32 increased it, in turn, displaces fluid in chambers 72a and 72b, increasing the pressure therein. At the same time, the volume of chamber 74 increases as a result of the radial contraction of actuator 32. The pressure in chamber 74, in turn, decreases. Valves 24a and 24b are closed, and valves 28a and 28b are open, allowing liquid to be expelled from chambers 72a and 72b through valves 28a and 28b. Similarly, valve ~~26a~~ 26b is opened and valve ~~26b~~ 26a is closed. Effectively, the pumping cycles of chamber72a and 72b are in phase with each other, and 180° out of phase with chamber 74.